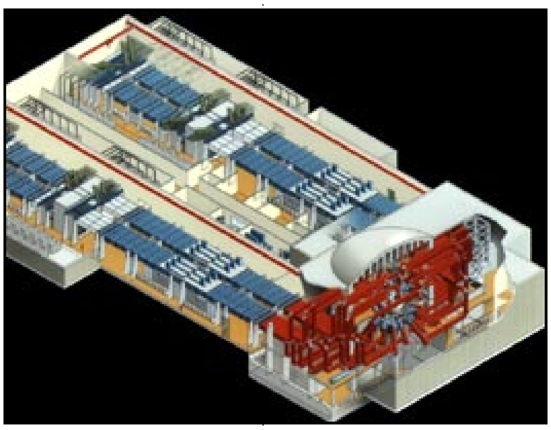
Lasers

Our contributions in laser technology and its applications range from new visions in industry and defense to improved vision for people, and from concept to design of the National Ignition Facility.

Imagination appears to be the only limit on the uses of the laser and related technologies. This is echoed by the Laboratory's efforts in science, technology, and engineering within the Laser Program. In the traditional laser-oriented portions of the program, these efforts range from thermonuclear physics to uranium enrichment for nuclear power plants. The program also encompasses the National Ignition Facility, which offers a science-based stewardship of our nation's nuclear stockpile and the promise of exciting research capabilities and high-technology jobs in the next century.



The proposed National Ignition Facility (shown here) will contribute to DOE's vision of science-based stockpile stewardship without underground testing.

Outside the traditional laser programs are other applications programs that have evolved because of needs that could be met by LLNL technologies. They include the Imaging and Detection Program, which explores defense and civilian applications in signal and image processing, detection theory, radar systems, remote sensing technologies, and airborne platforms, and the Advanced Microtechnology Program, which includes advanced lithography, magnetic storage, flat-panel displays, and micro-optics for human vision correction.

Inertial Confinement Fusion

The mission of the Inertial Confinement Fusion (ICF) Program is to develop a science and technology base that can demonstrate significant fusion energy yields in the laboratory and to identify and develop applications using that capability. For the near term, we are developing ICF technology to better understand issues in nuclear-weapon physics. A long-term goal is to explore ICF's feasibility as a clean and inexhaustible source for commercial electric power production by inertial fusion energy (IFE).

The National Ignition Facility

Conceptual design of the National Ignition Facility (NIF) was completed during the past year by a project team from Los Alamos, Sandia, and Livermore national laboratories. On October 21, 1994, the Secretary of Energy made a positive recommendation on Key Decision One, which, if accepted by Congress, would provide funding for detailed engineering design of the NIF starting in FY 1996. The Secretary also announced that DOE would hold a series of public meetings to address several issues, including the nuclear nonproliferation implications of the NIF. A positive assessment of NIF's value to the nuclear nonproliferation issue would be required prior to Key Decision Two, a commitment for construction.

The NIF's neodymium glass laser will supply about 1.8 MJ of energy, at a wavelength of 351 nm, to a fusion target. The laser will consist of 192 individual beams in 48 four-beam groups. In 1994, the NIF baseline multipass architecture was verified on a single aperture of the Beamlet scientific prototype system. This system, operating at a wavelength of 1053 nm, produced fluences equivalent to those required for the NIF and achieved excellent beam quality (in terms of low peak-to-average fluence modulation and small wavefront aberration). The Beamlet's output beam was converted to the third harmonic at a wavelength of 351 nm, demonstrating the NIF harmonic conversion efficiency and fluence requirements.

Nova Experiments

We continued our collaboration with Los Alamos National Laboratory on the 12 ignition-physics goals defined by the Nova Technical Contract.[1] This past year we demonstrated, using

Nova, five critical parameters of NIF hohlraums (cavities that convert the energy in laser beams to a near-isotropic bath of soft x rays for imploding the fusion fuel capsule):

- Soft x-ray, black-body radiation temperatures up to 300 eV.
- Time-averaged symmetry of soft x-ray radiation drive to a few percent.
- Low levels of backscattered laser light from plasmas similar to those in NIF hohlraums, which indicate efficient energy coupling to the target.
- Implosions with convergences (the ratio of fuel capsule's initial to final radius) up to 24 with little fusion-generated neutron yield degradation.
- Hydrodynamic growth factors up to 100, values which are beginning to approach the calculated growth factors for NIF targets.

The partial declassification of the ICF program allowed the publication of four letters on the Nova x-ray drive experiments in the October 24, 1994, issue of *Physical Review Letters*.

We also collaborated with the University of Rochester on experiments relevant to direct-drive inertial-fusion designs. Other experiments on issues relevant to light-ion-driven targets were conducted by researchers from Sandia National Laboratories.

Target Development/Modeling

Our progress in ICF target design was significant. We focused our target modeling efforts on NIF-scale plasma physics, NIF target design, and time-dependent symmetry diagnosis; and we designed long-scale-length plasmas in both open (gas-bag) and closed (gas-filled-hohlraum) geometries to mimic anticipated NIF conditions. Plasma temperatures and densities were diagnosed by spectroscopic methods, and Nova experiments were performed to confirm all of the above. To calculate the interplay between filamentation instability and stimulated Brillouin scattering and to help explain Nova observations, we developed a three-dimensional plasma code. We also performed complex, fully integrated (hohlraum-plus-capsule) two-dimensional LASNEX simulations of three separate NIF target designs and developed new methods for diagnosing time-dependent drive symmetry, using x-ray-backlit, low-density foam balls.

To determine potential NIF uses for IFE development, we sponsored a national workshop and published major power-plant design studies based on heavy-ion drivers and diode-pumped solid-state lasers. We also contributed to the successful test of the Induction Linac Systems Experiment beam injector, which was completed at Lawrence Berkeley Laboratory.

Isotope Separation and Advanced Manufacturing Technology

Isotope Separation and Advanced Manufacturing Technology has two major

Highlights for 1994

Inertial Confinement Fusion

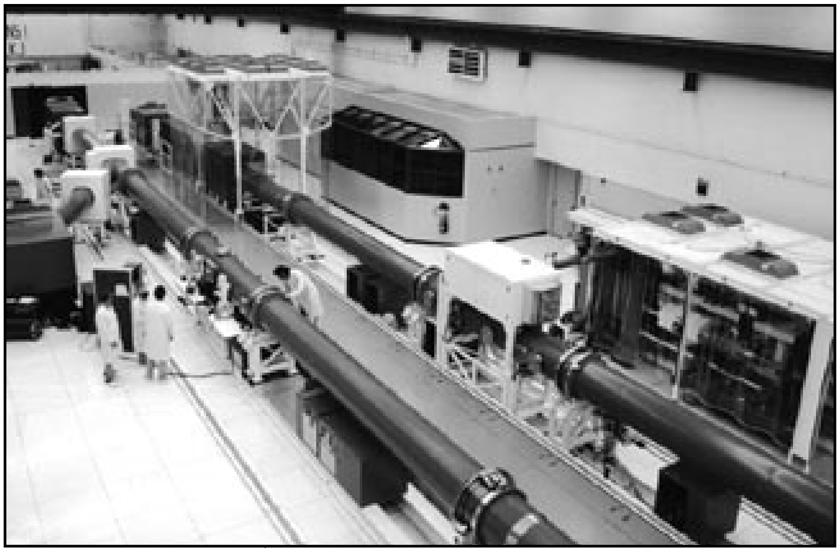
- Received the Secretary of Energy's positive recommendation on Key Decision One for the National Ignition Facility (NIF).
- Completed conceptual design of the NIF.
- Successfully demonstrated NIF performance with the Beamlet laser.
- Began demonstrating the scalability of target performance toward NIF-scale targets.

Isotope Separation and Advanced Manufacturing

- Established LLNL's largest-ever technology-transfer initiative with AVLIS when USEC began commercialization.
- Began large-scale gadolinium-enrichment experiments.
- Established CRADAs for E-beam and laser-materials processing technology-transfer activities.

Other Applications

- Successfully explored advanced concepts in imaging systems and applications.
- Used advanced microtechnology patents to obtain $50 million in new projects in lithography, information storage, and human vision correction.
- Developed high-average-power, diode-laser-based technology for x-ray lithography, remote sensing, materials processing, medical, and other applications.
- Deployed laser-guide-star adaptive optics system at Lick Observatory.



The Beamlet laser, a full-scale, single-beam prototype of the NIF design demonstrated laser fluences at infrared wavelengths equivalent to those required for the NIF.

programs: Atomic Vapor Laser Isotope Separation (AVLIS), which focuses on the enrichment and associated chemical processing of uranium and other heavy metal isotopes, and Advanced Manufacturing, which explores manufacturing applications of AVLIS technology.

AVLIS

The mission of AVLIS is to provide the world's lowest-cost, uranium-enrichment method for commercial power-plant fuel. With this method, precisely tuned laser light and uranium vapor are brought together in a separator vacuum assembly. In the separator, atoms of the ^{235}U minor isotope in an atomic vapor stream of natural isotopic composition are selectively optically excited and photoionized by laser light. The selectively ionized ^{235}U isotope is then collected to generate a product enriched in this isotope. Once enriched, the metal product is processed into nuclear fuel.

Uranium AVLIS is now funded solely by the United States Enrichment Corporation (USEC). In July 1994, USEC's board of directors voted unanimously to begin commercializing AVLIS, not only ensuring its continuance, but making it the largest and most significant technology-transfer initiative in LLNL history. The USEC also accepted an AVLIS proposal to use the same hardware and technology to investigate the enrichment of gadolinium in the odd isotopes ^{155}Gd and ^{157}Gd. Natural gadolinium is used as a burnable absorber in light-water nuclear power plants. The odd isotopes have much larger absorption cross sections for thermal neutrons than the even isotopes. The use of an isotopic mixture enriched in the odd isotopes in place of a natural isotopic mixture as a burnable absorber would improve the economics of light-water reactor operations. Sales of enriched gadolinium are projected at approximately $100 million per year.

Laser Activities. Laser technology development continued to support the future deployment of an AVLIS plant. Efforts continued to eliminate the chlorofluorocarbons (CFCs) used to cool electronic components in the copper laser system. Our latest laser oscillator eliminates CFCs in favor of air and water cooling, and our newest amplifier eliminates CFC cooling of the high-voltage power supply. We also have been developing a method for cooling the amplifier pulse-power modulator—a challenge because of its high average power (nearly 100 kW), high output voltage (80 kV), and short risetime (tens of nanoseconds). Tests of promising oil-cooled modulators will be completed soon, allowing system retrofits to begin.

We also installed and are activating the Plant-Scale Dye Laser System (PDLS), a full-scale version of an AVLIS plant's dye laser module. All copper pump light in the PDLS is supplied by large-core optical fibers. Hybrid refractive/refractive telescopes (which reduce the dye chain's length as much as 50%) transport dye laser beams through the optical system. Alignment of both the copper and dye laser beams is remotely monitored and controlled.

Separators. We focused our attention on activating a second-generation separator pod. The run duration (more than 260 hr) and throughput rate (near plant value) achieved by this pod in 1993 were records for AVLIS and represented important steps toward our goal of 600-hr pod lifetimes. We operated the pod again in 1994 for gadolinium vaporization, modifying the electron-beam magnetic transport system to minimize the magnetic field in the photozone. The pod operated smoothly and easily produced the desired gadolinium vaporization rates.

Advanced Manufacturing

Electron-Beam Materials Processing. We are using AVLIS technology to produce injection molds currently manufactured by expensive and time-consuming conventional and electric-discharge machining. In this new process, an electron-beam vaporizer deposits metal on a mandrel (or negative of the desired mold). By carefully controlling vaporization parameters and the mandrel temperature, we can build up 1-cm-thick deposits in a few hours. We have already produced several demonstration molds and have entered into a CRADA with industry to develop and commercialize this technology.

We are using new diode-laser-based sensors to monitor and control the vapor composition of complex alloys whose components have widely varying vapor pressures. Controlling the vapor composition extends the use of electron-beam evaporation (which produces the highest coating rates of any physical vapor-deposition process) to the manufacturing of complex alloys. The same technology is being used to manufacture metal-matrix composite materials for the U.S. aerospace industry.

Laser Materials Processing. We are using beams from our copper, dye, and diode-pumped solid-state lasers for advanced manufacturing. By combining diffraction-limited beam quality with precision laser-beam scanning technology, we can drill circular holes of 100 to 200 μm in diameter through 1-mm-thick stainless steel with better than 10-μm accuracy. We can also drill noncircular holes with almost arbitrarily shaped (such as square or triangular) cross sections, which gives laser machining a unique advantage over electric-discharge machining.

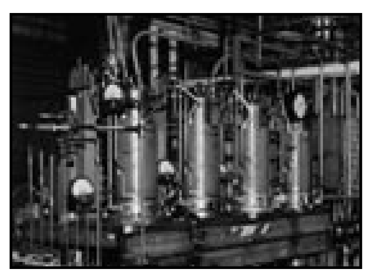
We use pulsed-laser ablation to produce high-quality, diamond-like carbon films for flat-panel displays, artificial joints for human prostheses, and nonferrous tools. With copper vapor lasers, which produce laser radiation in the visible wavelength at high pulse-repetition rate and high average power, we have increased film growth rates by a factor of 100 over other laser or chemical vapor-deposition methods, potentially reducing film costs.

Imaging and Detection

LLNL is technical manager of U.S. activities in the Imaging and Detection Program's (IDP's) largest project, the joint U.K./U.S. Radar Ocean Imaging Program, which studies the use of radar to detect surface manifestations of moving submarines and surface ships. IDP's main goal is to assess submarine detectability by airborne and spaceborne radars, using a comprehensive model constructed from fundamental physics considerations, statistical models, and empirical data.

The IDP is also responsible for the Super-High-Altitude Research Project, the world's largest light-gas gun of its kind. This gun, which was originally designed to launch payloads into space, uses a fuel–air combustion first stage to drive a piston that heats and compresses a hydrogen-fueled second stage. We have been using the gun to launch 6-kg projectiles and have




The major components of AVLIS technology include lasers (two photos top and middle left), separators (bottom left), computers and controls (top right), and uranium processing (bottom right).

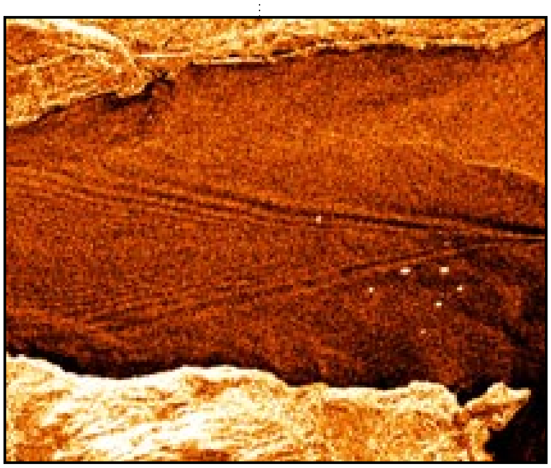
established a world-record kinetic energy of 24 MJ at a projectile velocity of more than 2 km per second. In collaboration with Rockwell International, we also set a benchmark for supersonic combustion ramjet (SCRAMJET) performance, achieving inlet start (at a speed of Mach 8) for a hydrogen-fueled projectile. Future side-injected light-gas guns could reduce the cost (by a factor of 20) of placing G-hardenable payloads into space.

Currently, we are working on a prototype ultrawide-bandwidth, remote-sensing, impulse radar system for high-resolution microwave imaging, as well as associated algorithms for image formation. The system, which will also be used for wave-tank studies of ocean-wave scattering physics and for detecting and imaging personnel in closed rooms or buildings, will extend our high-resolution radar-imaging capabilities from meters to centimeters and allow us to form recognizable targets for defense or law-enforcement applications. It will also allow us to do detailed studies of scattering physics, provide accurate spill and contaminant mapping, and enhance sensitivity for detecting ocean currents and wave spectra.

Advanced Microtechnology

The Advanced Microtechnology Program (AMP) is one of the fastest growing industrial outreach activities at LLNL. In its largest project, extreme ultraviolet lithography, AMP collaborates with two other national laboratories and eight industrial partners. The goal of the project is to provide a capability for short-wavelength (13-nm) projection lithography for the mass production of integrated circuits having features of 0.13 μm and smaller. Other projects include

L-band synthetic-aperture-radar image of a surface-ship-generated internal wave.



- An advanced magnetic head (patent pending) for use in computer hard-disk storage systems that should be more sensitive and less costly than current magnetic heads and increase storage density by a factor of 200.
- A flat-panel display project to produce field-emission display structures that, because of AMP's capability in submicron interference lithography, should be brighter, faster, and less costly than liquid-crystal displays.
- A microthin (about 25.4-μm-thick) lens for the human eye, which should correct the chromatic aberrations normally associated with diffractive optics, could potentially make conventional cataract surgery obsolete and might eliminate the need for conventional eyeglasses and contact lenses.

Other Activities

Average-Power, Solid-State Laser Technology

In concert with government and industry, we have been developing compact and efficient solid-state lasers to extend the state of the art in average-power, solid-state laser technology. The development of laser-diode array packages (diodes, microchannel coolers, and microlenses for beam collimation) that produce high-average powers in the near-infrared continues to be an important part of the program. These packages can be stacked together to produce multikilowatt laser arrays for direct use or for pumping other solid-state lasers. Efforts are currently ongoing to transfer this capability to industry.

During the past year we built average-power, solid-state lasers for several applications, such as the advanced illuminators now being tested for military applications. Our advanced lasers were also used in the industrial sector for R&D in semiconductor lithography, materials processing, and medical treatments. In addition, we continued to improve our base laser capability, extending our diode capability toward the blue-wavelength region and demonstrating a record 360 W/cm^2 of continuous output power at 690 nm. We also produced a 2-kW, peak-power, diode-array operating at 900 nm for pumping a ytterbium-doped crystal of potential use for inertial fusion energy.

Laser Guide Star

The laser guide-star project develops technology to implement adaptive-optics systems on ground-based telescopes, using laser-generated guide stars in the upper atmospheric sodium layer to correct the effects of atmospheric turbulence and improve resolution. Last year, we began construction of a smaller version of the AVLIS dye laser system that had demonstrated the brightest sodium-layer laser guide star in 1993, and we operated a natural guide-star adaptive-optics system at the University of California’s Lick Observatory. The laser, control system, and launch telescope are still being constructed. The dye laser will be mounted directly on the 3-m-aperture Shane telescope at Lick and energized by light that is delivered by optical fibers from remotely located solid-state lasers. The adaptive optics system, which forms the other major guide-star subsystem, was operated on the 1-m Nickel telescope at the Lick Observatory and corrected resolution by an order of magnitude. It has since been relocated to the Shane telescope for use with the new laser system in FY 1995 and has already improved the resolution capability using natural guide stars. This laser guide-star system is expected to produce near-diffraction-limited performance for observations in the near-infrared region.

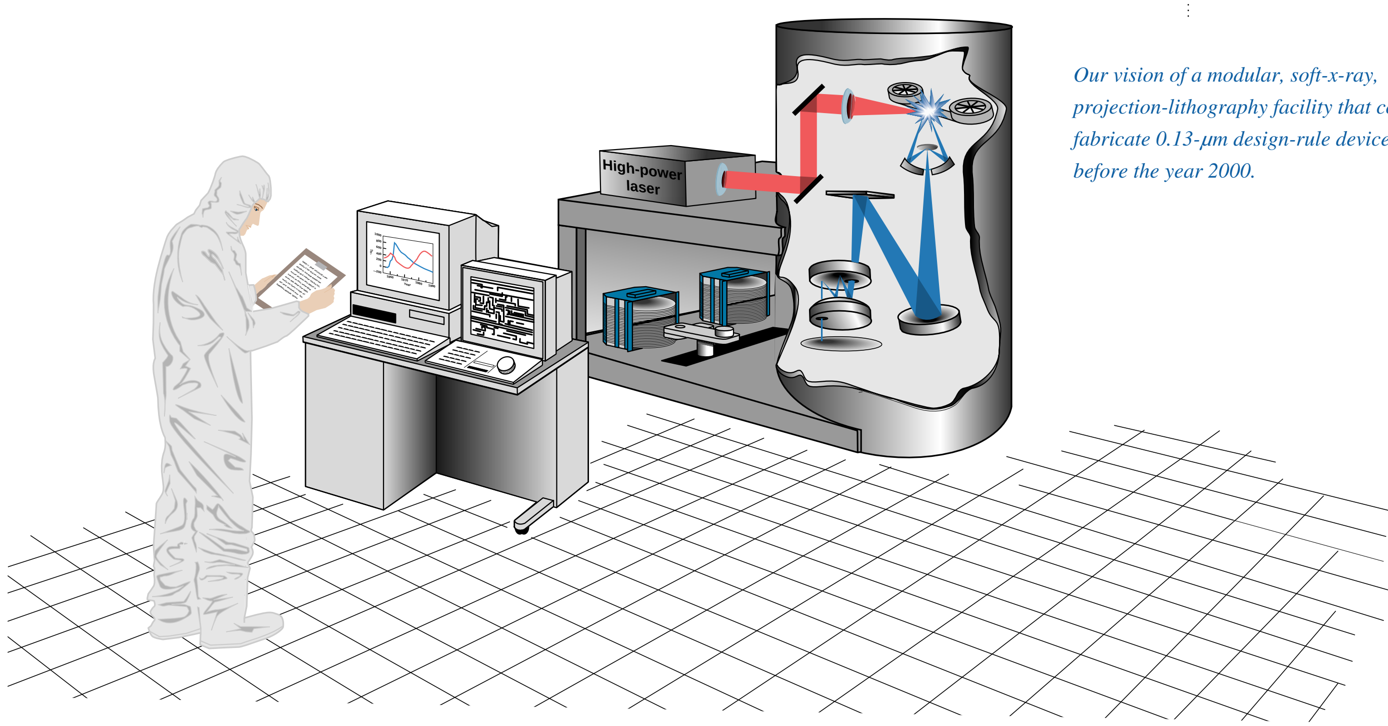
Summary

The scope of our research in laser and related technologies has grown over the years and has attracted a broad user base for applications within DOE, DOD, and private industry. Within the next few years, we expect to begin constructing the National Ignition Facility, to make substantial progress in deploying AVLIS technology for uranium and gadolinium enrichment, and to develop new radar sensing techniques to detect underwater objects. Further, we expect to translate LLNL patent ideas in microlithography into useful industrial products and to successfully apply high-power, diode-based laser technology to industrial and government applications.

Reference

1. National Research Council, *Second Review of the Department of Energy’s Inertial Confinement Fusion Program*, Final Report (National Academy Press, Washington, D.C., 1990).

For further information contact E. Michael Campbell (510) 422-5391 or Hao-lin Chen (510) 422-6198.



Our vision of a modular, soft-x-ray, projection-lithography facility that could fabricate 0.13-μm design-rule devices before the year 2000.